Empirical Research and Evaluation on Capability of Port Logistics Based on Fuzzy Comprehensive Evaluation Method

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Abstract

Port is an important junction of international transportation logistics. It is an important constituent part of modern industry of logistics. Scientific evaluation on ability of port logistics is an important premise of self-positioning of port and coordinating the development of regional economy. This paper firstly expounds the definition, features, functions and structure of port logistics, further expounds the ability of port logistics and analyzes its formation basis. Based on simulated comprehensive evaluation method, port logistics capability evaluation index system and fuzzy comprehensive evaluation model are built. The model is used for empirical research on the logistics capability of a port newly built. This paper applies the theoretical concept of port’s logistics capability and evaluation method to practical port and offers quantitative theoretical reference to the evaluation on ability of port logistics. This can be guidance to the healthy development of ports in China.

Keywords: Simulated comprehensive evaluation method, Ability of port logistics, Evaluation indexes, Evaluation model, Empirical research.

1. INTRODUCTION

In the advocacy of national economic trade strategy, such as “one belt, one road”, total amount of international economic trades of our country increases year by year. Total amount of international goods transport becomes larger and larger. Port is the main logistics undertaker of international goods. More than 90% international goods are transported in waterway and port logistics. In statistics, cargo handling capacity of the ports of country reached 8 billion tons in 2010 (Zhou et al., 2011). The scale and economic benefit of port are determined by its logistics capability. Logistics capability is not only the representative of work efficiency of the whole port but also the reflection of core competitiveness of port enterprises. As the important junction of modern logistics system, port is facing a huge challenge in the fast change of international logistics system (Gabibova and Габибова, 2015).

With the increase of international goods transport, it is more and more significant to research the scientific research on the capability of modern port logistics. Foreign research on port trade started in the 1990s. Some scholars think port enterprises shall constantly improve their ability of coping with changeable demand, resources and international market competition (Chen and Yu, 2004). Some other scholars consider 32 possible factors and confirm 17 factors which influence logistics capability, including configuration capability, integration capability, balance capability etc. Domestic scholars have researched port logistics enterprises, the structure of logistics system and so on. They think port logistics capability reflects hardware and software facilities of logistics enterprises and reflects the enterprises’ capability of meeting customers’ requirements (Kotcharin et al., 2011).

This paper starts from theoretical knowledge, anew expounds the definition, features, systematical functions and systematical structure of port logistics, describes the concept, classification and structure of port logistics capability, builds the system of port logistics capability evaluation indexes following systematisms principle, hierarchy principle, feasibility principle and the principle of combining qualitative indexes and quantitative indexes, builds grade-1 comprehensive evaluation model and grade-2 comprehensive evaluation model, introduces the procedures of building model, applies the models in the practical evaluation on domestic certain port, gives evaluation scores to the port through confirming index weight and completes the empirical research on the port logistics capability based on fuzzy comprehensive evaluation method. The research in this paper has important guidance significance to exploring scientific and sustainable development of domestic ports. It is helpful for enterprises to well know their capability of port logistics.
2. THEORETICAL BASIS OF EVALUATION ON CAPACITY OF PORT LOGISTICS

2.1 Concept of port logistics

2.1.1 Definition of port logistics

Modern logistics is a comprehensive service system integrating transport, storage, loading and unloading, packaging, processing and logistics. As a key node of global logistic transport network, port is developing in the direction of offering all-round value-added service in modern logistics system. Because of particular and important logistic geographic position, port logistics is put forward as an independent concept. Generally speaking, port logistics means that coastal city utilizes its seacoast superiority and the software & hardware superiority of port enterprises to form radiant development with surrounding logistics network and complete goods collection, goods storage and goods distribution (Dou and Li, 2015).

2.1.2 Features of port logistics

Port logistics is different from other logistics industries. There are five features:

(1) The particularity of logistic products. In certain degree, port logistics offers intangible service. Satisfaction degree of customers is the feedback for the quality of port logistics.

(2) Port logistics is closely related to the development of local economy. Scale of economy and density of population determine the handling capacity of port.

(3) Development of port logistics is influenced by national strategy and international trading environment. For example, the strategies “one belt, one road” and “step out” advocated in recent years greatly promote the development of port logistics (Chen et al., 2015).

(4) Port logistics occupies central position in international logistics chain. Port is the junction of waterway transport. Waterway is the main part of international logistic transport. It determines the central status of port logistics.

2.1.3 Functions of port logistics

The functions of port logistics include traditional transport transfer, carry, storage, sorting, distribution and so on. In addition, port logistics has information processing function, business service and the function of tariff protection. Port logistics can promote and lead the economic development of the port area (Li et al., 2015).

2.1.4 The structure of port logistics

![Figure 1. Port logistics system diagram](image-url)
The structure of port logistics system is shown in Figure 1.

Port logistics system is comprised of regional environmental system, infrastructure system, logistics information system, business coordination support system, set distribution system and near the port industry system. They supplement each other, closely relate to each other and jointly form port logistics system (Sohn, S. Y. et al., 2007).

2.2 Capacity of port logistics

2.2.1 The concept of capacity of port logistics

In one aspect, capacity of port logistics is the capacity of storing, transferring and distributing goods in port; in another aspect, it is the number of customers in port, storage capacity, goods circulation capability, capability of internal primary processing and distribution and other operation management capability. It can also be thought to be the capability of port enterprise offering logistic service and the capability of generating profits in certain period (Yang et al., 2009).

2.2.2 The basis of forming capacity of port logistics

(1) Realistic basis: With progress of the process of modernization and the development of international trade in our country, port gradually becomes a key logistic node of international trade. Modern port is an industry in production, trade and transport. It integrates logistic node and promotes the development of local economy.

(2) Economic base: Economic globalization and e-commerce trade develop rapidly; demands of logistics customers are diversified; the competition among logistic enterprises becomes fiercer. They form present typical external environment of logistics economy. The external environment requires port enterprises to have better capability of matching logistics of upstream enterprises, midstream enterprises and downstream enterprises.

(3) Social basis: Port is the junction of water and land transportation, platform of logistics and support of urban industry. There are two functions of port to city: one is to offer a way to external transport; the other is to drive development of relevant industries. Port is the infrastructure of national economy. Its economic benefit is not obvious. It produces economic benefit through playing social benefit. For reasons, port can not only gather production factors of city but also introduce the production factors needed by industry and trade. It brings new investment, new industries and new trade (Cho et al., 2006).

(4) Industrial base: At present, technical innovation and operation expansion are the main methods of improving capacity of port logistics. Advanced computer can be used to timely sort and process frequent and small orders, expand business operation and lay new industrial foundation.

3. PORT LOGISTICS CAPABILITY EVALUATION MODEL

3.1 Port logistics capacity evaluation index system

The premise of evaluating port logistics capacity is to confirm the indexes which influence port logistics capacity. It is also the first link of building evaluation model. The selection of evaluation indexes plays key functions to the evaluation on capability of port logistics.

In the process of selecting evaluation indexes, systematism principle, hierarchy principle, feasibility principle and the principle of combining qualitative indexes and quantitative indexes are followed. The evaluation index system is made to be forward-looking. At the same time, it reflects the features and potential factors of the upstream, midstream and downstream of port logistics, scientifically analyzes capability of port logistics and offers management strategy to port managers (Ji and Chu, 2012).

Integrating above principles and evaluation thoughts, port logistics capacity evaluation index system can be got in table 1. In the table, port logistics index system is defined to be U. Its 6 main components are: U1, U2, U3, U4, U5, U6. The indexes are divided into grade-1 indexes and grade-2 index (Xie et al., 2015).
Table 1 Port logistics evaluation index system

<table>
<thead>
<tr>
<th>Port logistics evaluation index system</th>
<th>I class index</th>
<th>II class index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Port environment $U_1$</td>
<td>The economic environment in which the port is located $U_{11}$</td>
<td>Degree of Liberalization and Internationalization of Cities in Ports $U_{12}$</td>
</tr>
<tr>
<td>Port location conditions $U_2$</td>
<td>Port location $U_{21}$</td>
<td>Direct economic hinterland total port $U_{22}$</td>
</tr>
<tr>
<td>Port infrastructure $U_3$</td>
<td>Port climate and natural conditions $U_{31}$</td>
<td>Container handling equipment capacity $U_{33}$</td>
</tr>
<tr>
<td>Port operating conditions $U_4$</td>
<td>The level of the port rate $U_{41}$</td>
<td>Management and service agencies to improve the degree $U_{42}$</td>
</tr>
<tr>
<td>Port gathering conditions $U_5$</td>
<td>Harbor dredging loading average parking time $U_{51}$</td>
<td>Highway collection and distribution capacity $U_{52}$</td>
</tr>
<tr>
<td>Logistics service level $U_6$</td>
<td>Management information system $U_{61}$</td>
<td>Security monitoring system $U_{62}$</td>
</tr>
</tbody>
</table>

3.2 Fuzzy comprehensive evaluation model for port logistics

3.2.1 Grade-1 fuzzy comprehensive evaluation model

There are 7 steps of building grade-1 fuzzy comprehensive evaluation model (Fu, P. H., & Yin, H. B., 2012):

Procedure 1: Build evaluation index system set $U = \{u_1, u_2, ..., u_n\}$. $u$ is influencing factors or evaluation indexes;

Procedure 2: Build evaluation set $V = \{v_1, v_2, ..., v_m\}$ corresponding to evaluation index system;

Procedure 3: Evaluate every factor in index system and confirm degree of membership corresponding to evaluation set to get evaluation vector $r_i = [r_{i1}, r_{i2}, ..., r_{im}]$;

Procedure 4: Evaluate all factors in index system and get evaluation matrix $R$. $R$ is the fuzzy relation from $U$ set to $V$ set:

$$ R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix} \quad (1) $$
Procedure 5: Confirm the weight of each factor in set. Weight vector is \( A = \{a_1, a_2, ..., a_n\} \). \( a_i (i=1, 2, ..., n) \) is the importance degree in comprehensive evaluation.

\[
\sum_{i=1}^{n} a_i = 1, a_i > 0
\]  

(2)

Procedure 6: Fuzzy comprehensive evaluation. Evaluation vector is \( B = A \cdot R = (a_1, a_2, ..., a_m) \cdot \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix} = (b_1, b_2, ..., b_m) \). Normalize it to be: \( \sum_{j=1}^{m} b_j = 1 \).

Procedure 7: Get evaluation conclusion.

3.2.2 Grade-1 fuzzy comprehensive evaluation model

There are 2 grades of index evaluation system. Corresponding each factor of fuzzy comprehensive evaluation model is at 2 grades. In this way, the weight of each factor can be accurately confirmed and the evaluation result can be accurate (Jin, J. L. et al., 2004). Grade-2 fuzzy comprehensive evaluation has 4 steps:

Procedure 1: Divide U to be S subsets:

\[
U_i = \{u_{i1}, u_{i2}, ..., u_{in}\}, i = 1, 2, ..., s
\]  

(3)

Procedure 2: Build evaluation set \( V = \{v_1, v_2, ..., v_m\} \);

Procedure 3: Grade-1 comprehensive evaluation. The weight vector of \( U_i \) is \( A_i \); evaluation matrix is \( R_i \); 1\( \times m \) order comprehensive evaluation vector \( B_i \) of \( U_i \) can be got.

Procedure 4: Grade-2 comprehensive evaluation. Every \( U_i \) of set U reflects an attribute of U. Set \( A = \{a_1, a_2, ..., a_s\} \) is distributed according to its importance degree. \( B_i \) is the evaluation vector of each \( U_i \). A \( s \times m \) order evaluation matrix \( R \) can be formed.

Weight vector \( A \) directly influences the result of comprehensive evaluation. Analytic hierarchy process is used in this paper to confirm weight vector. In analytic hierarchy process, \( n \) evaluation factors are arranged to be a \( n \)-order evaluation matrix; through comparison of them, the value of factors in the matrix can be confirmed according to importance degree of each factor; then calculate the largest eigenvalue and corresponding eigenvector of the evaluation matrix, namely weight vector required (Liang, Z. et al., 2006).

(1) Select two elements in set to make weight comparison

<table>
<thead>
<tr>
<th>Code</th>
<th>Importance level</th>
<th>( x_{ij} ) assignment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Two elements are equally important</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>i a little important than j</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>i obviously important than j</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>i strongly important than j</td>
<td>7</td>
</tr>
<tr>
<td>5</td>
<td>i extremely important than j</td>
<td>9</td>
</tr>
<tr>
<td>6</td>
<td>i a little unimportant than j</td>
<td>1/3</td>
</tr>
<tr>
<td>7</td>
<td>i obviously unimportant than j</td>
<td>1/5</td>
</tr>
<tr>
<td>8</td>
<td>i strongly unimportant than j</td>
<td>1/7</td>
</tr>
<tr>
<td>9</td>
<td>i extremely unimportant than j</td>
<td>1/9</td>
</tr>
<tr>
<td>10</td>
<td>The important ratio of the two elements is between the two adjacent ranks</td>
<td>2, 4, 6, 8, 10</td>
</tr>
<tr>
<td>11</td>
<td>The unimportant ratio of the two elements is between the two adjacent ranks</td>
<td>1/2, 1/4, 1/6, 1/8, 1/10</td>
</tr>
</tbody>
</table>

Table 2 Judgment of importance degree of two elements
Set \( x_{ij} = f(U_i/U_j) \) to be the judgment value of importance degree of \( U_i \) to \( U_j \). Table 2 is the judgment of importance degree of two elements.

(2) Build judgment matrix

Judgment matrix is formula 4:

\[
X = \begin{bmatrix}
    x_{11} & x_{12} & \cdots & x_{1n} \\
    x_{21} & x_{22} & \cdots & x_{2n} \\
    \vdots & \vdots & \ddots & \vdots \\
    x_{m1} & x_{m2} & \cdots & x_{mn}
\end{bmatrix}, \quad x_{ii} = 1, \quad x_{ij} \ast x_{ji} = 1
\]  \hspace{1cm} (4)

(3) Solve to get the largest eigenvalue \( \lambda_{\text{max}} \) and corresponding eigenvector of matrix \( X \), calculate consistency index \( CI \) and average random consistency index \( CR \):

\[
CI = \frac{\lambda_{\text{max}} - n}{n-1}
\]  \hspace{1cm} (5)

\[
CR = \frac{CI}{RI}
\]  \hspace{1cm} (6)

Select the value of RI after repetitive 1000 computations. If \( CR < 0.1 \), it indicates the judgment matrix has satisfying consistency.

\[
B = A \cdot R = \begin{bmatrix} B_1 \\ B_2 \\ \vdots \\ B_m \end{bmatrix} = \begin{bmatrix} A_1 \cdot R_1 \\ A_2 \cdot R_2 \\ \vdots \\ A_m \cdot R_m \end{bmatrix} = (b_1, b_2, ..., b_m)
\]  \hspace{1cm} (7)

In above calculation process, a certain blurring operator is needed for getting a comprehensive evaluation model. There are many factors of port logistics capacity evaluation. To make evaluation result scientific and reliable, \( M(\cdot, \Theta) \) is selected to be average weighing fuzzy operator. \( b_j = \sum_{i=1}^{m} a_{ij}r_{ij} (j = 1,2, \ldots, n) \).

(4) After getting grade-2 comprehensive evaluation vector \( B \), method of weighted mean is used to confirm the final evaluation result. In the principle of largest degree of membership, \( V_j \) corresponding to \( b_j \) is selected to be evaluation result (Liu et al., 2011).

4. EMPIRICAL RESEARCH ON EVALUATION ON PORT LOGISTICS CAPACITY

4.1 Empirical evaluation on port logistics capacity based on fuzzy comprehensive evaluation

A domestic coastal port is selected as research object. According to the evaluation index system in table 1, there are 6 grade-I indexes and 27 grade-II indexes in the evaluation index system.

1. Build evaluation set. There are five grades of evaluation set: \( V = \{ v_1, v_2, \ldots, v_5 \} \). They respectively represent “very good”, “good”, “normal”, “bad” and “very bad”.

2. Confirm weight of indexes

For grade-1 index weight, 50 questionnaires are distributed to port managers and service objects in port. 43 questionnaires are retrieved. Fuzzy comprehensive evaluation questionnaire is shown in Table 3.

The weight of other grade-2 indexes are confirmed in the same way. Judgment matrix is got in the value assignment way in Table 2. For example, the value assigned in comparison between B- and C+ is 2. Grade-1 index judgment matrix can be got:
Table 3 Fuzzy comprehensive evaluation questionnaire

<table>
<thead>
<tr>
<th>Class index evaluation table</th>
<th>Very important</th>
<th>Important</th>
<th>General</th>
<th>Unimportant</th>
<th>Very unimportant</th>
</tr>
</thead>
<tbody>
<tr>
<td>A+</td>
<td>0.1000</td>
<td>1.1067</td>
<td>0.2817</td>
<td>0.2903</td>
<td>0.2486</td>
</tr>
<tr>
<td>A-</td>
<td>1.0000</td>
<td>0.3324</td>
<td>0.32</td>
<td>1</td>
<td>0.5426</td>
</tr>
<tr>
<td>B+</td>
<td>0.4000</td>
<td>3.2400</td>
<td>1.0000</td>
<td>3.0084</td>
<td>1.8798</td>
</tr>
<tr>
<td>B-</td>
<td>3.4447</td>
<td>1.1400</td>
<td>0.3324</td>
<td>1.0000</td>
<td>1.9164</td>
</tr>
<tr>
<td>C+</td>
<td>3.6000</td>
<td>1.8430</td>
<td>0.5320</td>
<td>0.5218</td>
<td>1.0000</td>
</tr>
<tr>
<td>C-</td>
<td>2.0500</td>
<td>0.5282</td>
<td>0.2453</td>
<td>0.4930</td>
<td>0.3475</td>
</tr>
<tr>
<td>Port location conditions U_2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Port operating conditions U_3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Port infrastructure U_4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Port gathering conditions U_5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Logistics service level U_6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The following evaluation matrixes can be got according to the questionnaires of port logistics capacity evaluation:

\[
\begin{align*}
R_{U_1} &= \begin{bmatrix} 11 & 19 & 7 & 3 & 0 \\ 40 & 40 & 40 & 40 & 0 \\ 40 & 40 & 40 & 40 & 0 \\ 13 & 15 & 9 & 2 & 1 \\ 40 & 40 & 40 & 40 & 0 \end{bmatrix}, \\
R_{U_2} &= \begin{bmatrix} 3 & 8 & 2 & 0 & 0 \\ 40 & 40 & 40 & 40 & 0 \\ 40 & 40 & 40 & 40 & 0 \\ 40 & 40 & 40 & 40 & 0 \\ 40 & 40 & 40 & 40 & 0 \end{bmatrix}, \\
R_{U_3} &= \begin{bmatrix} 0 & 2 & 3 & 1 & 0 \\ 40 & 40 & 40 & 40 & 0 \\ 40 & 40 & 40 & 40 & 0 \\ 40 & 40 & 40 & 40 & 0 \\ 40 & 40 & 40 & 40 & 0 \end{bmatrix},
\end{align*}
\]

\[
\begin{align*}
R_{U_4} &= \begin{bmatrix} 2 & 8 & 10 & 15 & 5 \\ 40 & 40 & 40 & 40 & 0 \\ 13 & 10 & 8 & 2 & 0 \\ 40 & 40 & 40 & 40 & 0 \\ 40 & 40 & 40 & 40 & 0 \end{bmatrix}, \\
R_{U_5} &= \begin{bmatrix} 6 & 12 & 11 & 8 & 3 \\ 40 & 40 & 40 & 40 & 0 \\ 12 & 11 & 8 & 6 & 3 \\ 40 & 40 & 40 & 40 & 0 \\ 11 & 12 & 10 & 5 & 2 \end{bmatrix}, \\
R_{U_6} &= \begin{bmatrix} 2 & 8 & 10 & 15 & 5 \\ 40 & 40 & 40 & 40 & 0 \\ 13 & 10 & 8 & 2 & 0 \\ 40 & 40 & 40 & 40 & 0 \\ 20 & 18 & 2 & 0 & 0 \end{bmatrix},
\end{align*}
\]

The largest eigenvalue of the matrix is \( \lambda_{\text{max}} = 6.383 \). Consistency indexes: \( RI=1.26 \), \( CI=0.0766 \), \( CR=0.0608<0.1 \). They meet the requirement on consistency.

Similarly, weight value of the whole index system can be got. The weight vectors are:

\[
A_{U_1} = (0.1792, 0.5184, 0.1512, 0.1512),
\]

\[
A_{U_2} = (0.1620, 0.0693, 0.3261, 0.3261, 0.1232),
\]

\[
A_{U_3} = (0.0891, 0.2170, 0.2170, 0.1811, 0.1479, 0.1479),
\]

\[
A_{U_4} = (0.3873, 0.1504, 0.0760, 0.3873),
\]

\[
A_{U_5} = (0.2304, 0.2703, 0.2976, 0.2017), \quad A_{U_6} = (0.3278, 0.3278, 0.2106, 0.1238)
\]

The following evaluation matrixes can be got according to the questionnaires of port logistics capacity evaluation:

\[
B_i = A_{U_i} \cdot R_{U_i}
\]
In grade-2 comprehensive evaluation, normalize calculation result and fuzzy comprehensive evaluation set can be got:

$$B' = (0.2681, 0.3219, 0.2280, 0.1342, 0.0479)$$

**4.2 Result of port logistics capacity evaluation and the analysis on it**

According to the five grades of evaluation set: “very good”, “good”, “normal”, “bad” and “very bad”, there are five score intervals: [90, 100], [80, 90], [70, 80], [60, 70] and [40, 60]. Median of core interval is selected for calculating the final scoring result. $C=(95, 85, 75, 65, 50)^T$; capacity of port logistics $P=B' \cdot C=81.04$ in the internal [80, 90]. It is at high level of logistics capacity.

The enlightenment from evaluation on capacity of port logistics is to accelerate logistic network construction and informatization construction of port, strive for support of government’s policy, improve system of goods source, implement differential pricing strategy, increase hardware investment, further promote the integration development of port and regional economy, raise soft service level of logistics and stimulate port to develop to be free trade zone.

**5. CONCLUSIONS**

Capacity of port logistics is a key index of evaluating development and management of port. It is the necessary premise of development of port to evaluate capacity of port logistics in scientific and objective combination of the elements of regional development of port. On the basis of expounding relevant concepts of port logistics and capacity of port logistics, the system of port logistics capacity evaluation is built; the procedures of evaluation are introduced on the basis of fuzzy comprehensive evaluation method. Finally, an actual port is regarded as research object for empirical research. Main contents in this paper are listed below:

(1) The system of port logistics capacity index evaluation is divided with 6 grade-1 indexes and 27 grade-2 indexes, sufficiently considering the factors which influence capacity of port logistics and guaranteeing the validity of evaluation result.

(2) The procedures of building grade-1 and grade-2 fuzzy comprehensive evaluation model is introduced on the basis of fuzzy comprehensive evaluation. In addition, weight distribution is calculated.

(3) Empirical research is made taking a domestic port for example. Evaluation result is 81.04 following calculation procedures. It indicates high level of port logistics capacity.

**REFERENCES**


